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EC06-161 Chicory Production Guide with Emphasis on Field Production Practices for the Central High Plains

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Chicory Production Guide

With Emphasis on Field Production Practices for the Central High Plains

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Cover Photos

From the top down: A) Weeds can have a critical impact on chicory yield and need to be controlled within the first four weeks after planting. B) Being able to maintain a moist soil surface immediately after planting is critical to chicory germination, thus irrigation is usually essential. C) Root symptoms of bacterial root rot consist of a watery soft rot beginning at the distal tip of the tap root. Compare the two infected roots to the healthy root in the center. D) While insects are not a major threat to chicory production in Nebraska, cutworm populations can lower yields. E) Nebraska field trials indicate that nitrogen and sometimes phosphorus may need to be applied for optimum production.

Photos at Right

From the top down: A) Disease problems have not been a major threat to chicory yields in Nebraska, although bacterial root rot, as shown here, can be found at low levels in most fields. B) Grab roll cleaning beds in commercial chicory harvesters are hydraulically driven to allow the best compromise between the optimal rotational speed to reduce root breakage while providing soil removal. C) Rear view of commercial chicory harvester. Note very few root parts were left behind the harvester.

Chicory Production Guide

With Emphasis on Field Production Practices for the Central High Plains

Acknowledgment

The chicory industry that now exists in western Nebraska and southeast Wyoming has developed because of the vision, commitment and expertise of a number of individuals and organizations. The path for this industry development, starting formally with a phone call from Western Sugar Co. to the University of Nebraska–Lincoln in mid 1995, has had curves and has gone through new territory, but it has led to a multi-million dollar processing facility, local employment and a new crop for local growers. The University of Nebraska–Lincoln acknowledges significant contributors to this new chicory industry and those who have supported our involvement in this industry:

Western Sugar Co.
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Local chicory growers

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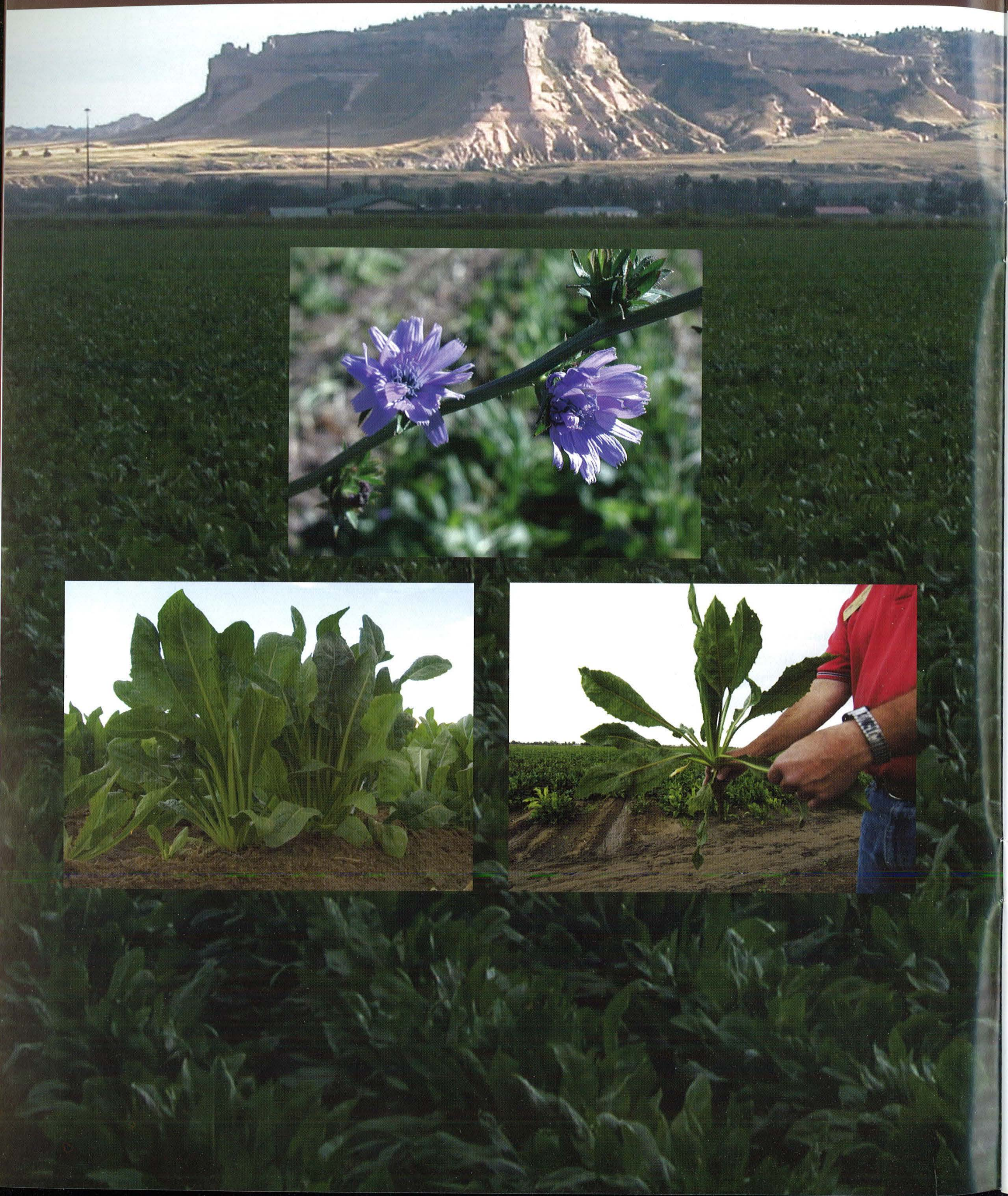


Introduction

By Robert G. Wilson and John A. Smith

Chicory can be categorized into three very general types or uses. The first type, *Cichorium endivia*, includes plants grown for their edible leaves such as escarole and curly endive. The second type, *Cichorium intybus*, includes plants grown for their edible leaves and roots. Witloof or Belgium endive roots are harvested and then grown in the dark to produce a blanched leaf that is eaten in salads. Industrial chicory is a subspecies, *sativum*, of *Cichorium intybus* that has been developed for its root. The roots of industrial chicory are dried and used in pet foods, roasted and used in drink flavoring, or processed to extract fructose and long chain fructose-based products termed fructo-oligosaccharides or inulin. These are industrial uses targeted for the chicory currently processed in Nebraska. The third chicory category is chicory grown as a forage crop for livestock.

Sustainable chicory production systems integrate cultural practices, pest management, farm equipment and crop production. ■

Industrial chicory production involves planting seed in spring so that the crop is established and growing by mid May. The establishment phase of plant growth is slow and seedlings must be protected from weed interference and insect damage. Once established, chicory plants put most of their energy into leaf growth until about mid July when canopy development slows and roots increase in size. Chicory planted in rows spaced 22 inches apart should cover the row and hence the soil surface by the first week in July. Root weight continues to increase throughout the growing season and reaches a peak during the first week of November. With good stand establishment and good weed control, growers in western Nebraska and southeastern Wyoming have achieved root yields of 18-22 ton/ac by late October. After mid November, soil temperatures are generally near freezing and root development ceases.

As soon as chicory plants start to intercept sunlight and photosynthesis begins, plants begin the conversion of sucrose to inulin. Inulin concentration and chain length in roots reach a peak in mid October. The occurrence of freezing temperatures after this period triggers the production of root enzymes that break down the long-chain inulin which allows the roots to overwinter without freezing.

Successful chicory production requires uniform plant establishment, water and nutrients for rapid growth and weed control to maximize sunlight interception. Once the crop has produced roots that meet the requirements of the processor, crop harvest can begin. This usually occurs from mid September through November. The authors of this production guide want to convey the importance of integrating cultural practices, pest management, farm equipment and crop production into sustainable systems of chicory production.

Field Selection

By John A. Smith

A number of factors should be considered before selecting a field for chicory production. The high input costs required by the chicory crop should not be put at risk by a poorly selected field. Field selection can make the difference between a good profit and a very frustrating season.

Irrigation Water Availability

Chicory will almost always require one, and usually two or three, irrigations immediately after planting to obtain an acceptable plant population. The field must have access to well water or surface water at the time of planting and through the growing season until the time of harvest. There must be ample soil water content at the time of harvest to avoid breaking the long root tails or there will be high harvest loss.

Irrigation Method

Either sprinkler or furrow irrigation systems will work for chicory. Row spacings greater than 22 inches should be avoided if using furrow irrigation because of the difficulty of saturating the soil in the row at seed depth during the emergence period. If surface residue is needed to prevent wind erosion, this residue will make furrow irrigation difficult. Sprinkler packages should be designed to minimize the creation of soil crust during irrigations for crop emergence.

Figure 1. *Commercial chicory field in July. Note the eight-row wide strips of corn used to minimize soil erosion early in the season when the chicory crop has little crop canopy.*

Soil Type

Chicory can be grown on most soil types. Soil textures vulnerable to wind erosion should be avoided or protected from wind erosion. Soils with high clay content may create root cleaning problems at harvest.

Previous Crop

The previous crop should be corn, dry edible beans or a small grain. Chicory should not be planted the year immediately following sugarbeet or chicory. Chicory following alfalfa could cause a problem with tillage, planting or cultivating unless the production system can manage the old alfalfa roots and any volunteer alfalfa. Use of a winter cereal cover crop for the emerging chicory carries a high risk of cutworm damage to the emerging chicory plants, and likely will require an insecticide treatment. (See *Insect Control* section.)

Weed Pressure

Because of limited herbicide options, avoid fields with a history of high weed pressure, particularly nightshade or common lambsquarters.

Wind Erosion

The chicory crop grows slowly during the first two months and wind erosion must be controlled until the crop is large enough to protect itself, sometimes until early July (*Figure 1*). Select fields that have low wind erosion potential and/or that have adequate surface residue to control wind erosion and blowing soil.

Herbicide History

Emerging chicory plants can be injured by small quantities of certain herbicides that may remain in the soil from use on previous crops. Check the plant-back restrictions on the herbicide label to see if herbicide carryover and crop injury are concerns. If the herbicide label does not list chicory in the plant-back restrictions, assume chicory would respond to herbicide residues in the soil in a similar manner as sugarbeet. Avoid fields that may contain a residual herbicide that may carry over in the soil and damage chicory. Such herbicides include Ally, Amber, atrazine, Glean, Peak, Spartan, Stinger and Tordon.

Fertilizer Management

By Gary W. Hergert

Most European literature suggests that root chicory requires nitrogen, phosphorus and potassium as well as magnesium and in some instances, boron for optimum yield. For Nebraska, nitrogen and phosphorus will be primary needs. Because western Nebraska soils are predominately high pH and have high base saturation, potassium and magnesium levels are high and soil and irrigation water sources usually contain sufficient boron for most crops.

Nitrogen

Proper nitrogen management is critical for optimal chicory production. Applying too little nitrogen will decrease yield potential and excess nitrogen will increase production costs and may affect root carbohydrate content. Nitrogen fertilizer recommendations can be improved by basing recommendations on residual nitrate in the soil. Chicory, like sugarbeet, has a deep tap root and can exploit nitrogen in the top 5 to 6 feet. Soil samples for residual nitrate-N should be taken from at least a 3- to 4-foot depth. *Table 1* provides suggestions for nitrogen application based on residual soil nitrate levels and soil organic matter. Based on agronomic literature and past research at the Panhandle Research and Extension Center in Scottsbluff, a simple algorithm for root chicory nitrogen rates is given.

Equation 1.

N rate = 200 - (30 x organic matter content) - residual soil nitrate (in 6 feet)*

*If soil samples are taken from less than 3 feet, no adjustment should be made. For sample depths of 3, 4 or 5 feet, divide the resulting pounds of nitrate-N in a depth (ppm x 3.6 x depth in feet) by the factor of 0.7 (3 ft), 0.8 (4 ft) or 0.9 (5 ft).

Table 1. Nitrogen fertilizer recommendations for chicory.

Residual Nitrate-N		% Soil Organic Matter	
ppm	lbs N/6 ft	1%	2%
		lbs N/ac to Apply	
2	50	120	90
4	90	80	50
6	130	40	20
≥8	170	0	0

The scientific literature does not indicate a great salt sensitivity for chicory; however, based on sugarbeet research, the fertilizer application should be split if nitrogen rates are greater than 100 lb/ac. Also, if fertilizer is broadcast applied and then beds are formed, nitrogen rates should not exceed 60 lb/ac to avoid potential seedling emergence problems.

Phosphorus

Many soils in western Nebraska and eastern Wyoming with a history of sugarbeet production have high levels of phosphorus. The European literature indicates that phosphorus response of chicory is similar to that of sugarbeet. Phosphorus fertilizer recommendations are provided in *Table 2.*

Table 2. Phosphorus fertilizer recommendations for chicory.

P Soil Test		Phosphate Fertilization
Bray-1	Olsen	
ppm		lbs P_2O_5/A to Apply
0-5	0-3	100
6-10	4-7	75
11-15	8-10	50
>15	>10	0

Potassium

Most soils in western Nebraska contain high potassium levels. If potassium levels are low, *Table 3* provides guidelines for potassium fertilization.

Table 3. Potassium fertilizer recommendations for chicory.

Potassium Soil Test	Potassium Fertilization
ppm K	lbs K_2O/A to Apply
0-40	120
41-74	80
75-124	40

Magnesium

The likelihood of a magnesium response in root chicory in this area is limited. European literature suggests magnesium rates of 25-50 lb/ac; however, no soil test levels are provided as a guide to application. Most western Nebraska soils are completely base saturated and have high extractable magnesium levels. Based on data from other root crops, if ammonium acetate extractable magnesium levels are less than 50 ppm, 25-50 lb/ac of magnesium from magnesium sulfate may be applied. Cation exchange capacity and cation ratios also may provide a guide. If soils have less than 5 to 10 percent magnesium saturation, additional magnesium may be required.

Boron

European literature indicates that if boron deficiency is a problem, a foliar spray at a rate of 2 lb of boron per acre may be recommended. Because most soils in the High Plains have adequate boron levels for other crops and there is some boron in irrigation water, it is unlikely that boron would be needed.

Primary Tillage

By John A. Smith

Chicory roots are very sensitive to soil compaction. What would be considered minor soil compaction for most other crops may cause the developing chicory root to grow horizontally and then downward again. This root "kink" will cause a high percentage of roots to break at or above the "kink" when the root is lifted during harvest. Field loss will reduce yield and substantially increase volunteer chicory problems in the following crop. Soil compaction also will decrease water intake for a sprinkler system, potentially causing runoff and reduced irrigation effectiveness.

At planting time, the soil should be free of identifiable soil compaction layers to a depth of at least 12 inches, preferably 14-18 inches. Moldboard plowing to at least 12 inches, or ripping to a depth of 14 or 16 inches when the soil water content is low, usually will alleviate any existing soil compaction layers. Ripping when the soil water content is moderate or high often will be ineffective for alleviating soil compaction and some other primary tillage method should be used. After moldboard plowing or ripping, secondary tillage systems must not recreate a compacted layer that could be even worse than the original compaction layer.

"Zone tillage" is an excellent alternative to the moldboard plow or broadcast ripping for primary tillage for chicory. This method tills only a narrow strip centered on the chicory row to be planted, and only to the depth needed to alleviate any soil compaction in the new row area. This controlled traffic system allows the root to develop without encountering compacted soil layers and does not incur the higher input costs associated with full-width tillage systems.

The zone tillage implement (*Figure 2*) must be equipped to completely close the shank mark in the soil and leave a firm, smooth and fine seedbed necessary for planting chicory. This system can include herbicide application and incorporation and an attached planter for a one-pass tillage-planting operation. A modified "Till-N-Plant" implement manufactured by Schlagel Manufacturing of Torrington, Wyoming has been successfully used for chicory production in Nebraska and Wyoming.

Figure 2. *Side view of the zone tillage implement used with the combined tillage-planting equipment system. Key elements are the coulter to cut-divide residue and soil for the shank; the shank intended to loosen the soil to a depth of at least 14 inches only in the row area; wavy coulters to close the shank mark; and rolling basket devices to level and firm the soil surface for planting.*

For furrow irrigated fields, fall or early spring bedding will facilitate irrigation after planting. The beds should be low, firm, and have a flat top. A shallow, but intensive, herbicide incorporation operation before planting will make these beds an ideal seedbed for chicory planting.

Seedbed Preparation

By John A. Smith

Because chicory seed must be planted very shallow (less than 3/8 inch) and must be accurately spaced, a "well prepared" seedbed is necessary for a good crop stand (*Figure 3*). The ideal seedbed is firm on the surface (but not compacted), level and free of large clods and excessive crop residue. The purpose of the final seedbed operation is to leave a surface that will allow the planter to be as accurate as possible. A loose surface, tillage ridges, large clods and large pieces of residue will not allow optimum planter performance. The firm, level surface also will help maintain the necessary soil water at seed depth by encouraging a uniform upward movement of soil water.

The final seedbed preparation operation should be conducted by an implement with closely spaced, narrow, vertical tines working to a depth of 2 or 3 inches. Rolling baskets and packer wheels with closely spaced elements also can be effective for the final operation. The preferred implement should cause horizontal soil movement and mixing, rather than inverting the soil to expose moist soil to evaporation and to create soil clods. These implements should leave the surface firm and level. Implements designed for preparing a seedbed for alfalfa or grass may work well for chicory. A series of rolling baskets on the back of a zone tillage implement also can prepare a good seedbed. A disk implement or a conventional roller-harrow do not provide an adequate seedbed for chicory because the surface soil is too loose, too uneven and often too cloddy.

The ideal seedbed is firm on the surface, level and free of large clods and excessive residue.

When planting on beds, the surface of the beds should be level, firm, and free of large clods and surface residue. A "Schmizer"-type roller or an implement with multiple rolling baskets can provide a good planting surface on beds.

Figure 3. *A well prepared seedbed can lay the foundation for an evenly spaced, full crop stand, as exemplified in this commercial chicory field which is almost at full canopy closure.*

Weed Control, Herbicides and Herbicide Incorporation

By Robert G. Wilson

Weeds have a tremendous impact on chicory root yield, especially those that become taller than the crop. Time of emergence has an impact on competitive ability; weeds emerging with the crop cause greater yield losses than weeds emerging later in the season. In experiments conducted in western Nebraska, a lack of early season weed control resulted in an 85 percent reduction in chicory root yield and demonstrated the susceptibility of chicory plants to early season weed competition. The first four weeks after planting are considered critical for weed removal to prevent crop losses. Chicory needs to be kept weed-free for approximately eight weeks after planting. After this period or in early July, the chicory canopy should be competitive enough to suppress newly emerging weeds. If the crop stand is poor or the crop is planted in a 30-inch row spacing, chicory may not suppress late emerging weeds and additional weed control measures may be necessary.

Several factors should be considered when planning a weed management program. Weed species, cover crop, preplant tillage, crop rotation, row spacing, cultivation, and herbicides all need to be integrated to develop an effective weed control strategy. Accurate weed identification should be the first step in the weed management program, and then care should be taken to match the best weed control strategy with the dominant weed pest.

The first four weeks after planting are critical for weed control. Nebraska research found that a lack of early season weed control resulted in an 85% reduction in chicory root yield. ■

Since chicory is a new crop in the United States, there are only a few herbicides approved for use in the crop. Treflan (trifluralin) is approved for use preplant incorporated. The herbicide needs to be mechanically incorporated in the upper two inches of soil. Treflan generally will control about 80 percent of the emerging grass and broadleaf weeds. This level of weed control is helpful but the uncontrolled weeds can still cause a 25 percent yield reduction. Therefore, additional weed control measures are needed to achieve optimum root production. Raptor (imazamox) is approved for application on chicory after the crop has emerged and reached the two true-leaf growth stage. Raptor must be applied to small weeds that are less than 3 inches in height to achieve optimum activity. The combination of Treflan at planting followed by Raptor postemergence will generally improve weed control to 90 percent or more. The remaining weeds are still competitive and need to be controlled with cultivation and hand weeding.

To achieve optimum root yields, growers need to use hand labor before row closure to remove weed escapes missed by herbicides and cultivation. A uniform plant population spaced in 22-inch rows will produce a dense leaf canopy by early July that can shade the soil and prevent late season weed development. Weedy grasses growing with chicory can be controlled with Select Max (clethodim) applied postemergence when grasses are less than 4 inches tall. Since weed control options in chicory are limited and weeds can cause substantial reductions in root yield, every effort needs to be used to suppress weed competition in the crop.

Reducing the weed population in crops grown before chicory can be an effective way of improving the performance of herbicides applied to chicory. If corn was grown the year before planting chicory, weed control was excellent and weeds were prevented from producing seed, research has shown that weed seedling emergence the next year can be reduced 40 percent. This example illustrates the potential benefits for controlling weeds in the preceding crop. Each spring about 12 percent of the weed seed in the soil germinates and emerges. If the quantity of seed emerging can be reduced by 40 percent, the number of weeds which must be controlled by the herbicide program is also reduced 40 percent. For example, assume the herbicide program controls 91 percent of the weeds and there are a million seeds per acre. In the corn field where weed control was excellent, the chicory grower would have 6,480 weeds per acre remaining after the herbicide program compared to 10,800 weeds per acre if weeds were not effectively controlled in the corn crop.

A second method of reducing weed density in the chicory crop is to control as many weeds as possible before planting chicory. This can be achieved by preparing the chicory seedbed as early as possible in the fall or spring. Remember to apply and incorporate Treflan when the seedbed is prepared. If soil moisture is lacking, pre-irrigation can cause weed seeds to germinate. Allow as many weeds to emerge as possible before planting, then spray the field with glyphosate. After spraying do not use any tillage before planting because tillage will cause more weeds to germinate.

Variety Selection, Seed Size and Seed Coating

By Robert G. Wilson

Seed is one of the most important factors in chicory production. Without a uniform plant population of a chicory variety adapted to the growing region (*Figure 4*), the producer will have difficulty achieving economical crop production.

Chicory seed is small — approximately 1/8 inch long by 1/16 inch wide. Because it is so small and light, the seed is generally pelleted to improve the accuracy of planting. Chicory seed can be purchased in three forms:

1) pellet seed (1 unit contains 100,000 seeds approximately 1/8 inch diameter; this is the seed normally planted in the United States);
2) mini-pellet seed (1 unit contains 250,000 seeds, approximately 1/16 inch diameter); and
3) coated seeds (1 unit contains 250,000 seeds).

It's extremely important that chicory varieties selected for production in the High Plains have good tolerance to bolting, which can be induced by freezing temperatures.

Chicory seed may be purchased treated with a fungicide to enhance seedling establishment. In the United States, only the fungicide Thiram (tetramethylthiuram disulfide) is approved for use on seed, and no other fungicides or insecticides are allowed.

Chicory seed is produced in Europe and is available from two companies: Florimond Desprez (*http://www.florimond-desprez.fr*) and Chicoline (*http://www.pype-seeds.be/fr/chicoline.html*). Each company has several varieties that are adapted for growing in the United States. Chicory varieties grown in the High Plains of the United States need to have good tolerance to bolting — the process of flowering — which is induced in seedlings by freezing temperatures. Root yield, root soluble dry matter content and bolting potential will vary among varieties. Root yields of several varieties adapted for use in the High Plains are presented in *Table 4*. Resistance to bolting is extremely important; less than 0.5 percent of the plants at harvest should have bolted.

Table 4. Historical root yield and soluble dry matter of different chicory varieties tested at Scottsbluff, NE from 2001 to 2004.

	Root Yield						Soluble Dry Matter					
Chicory Variety	2004	2003	2002	3 yr avg	2001	4 yr avg	2004	2003	2002	3 yr avg	2001	4 yr avg
	(tons/acre)						(%)					
Orchies	25.3	24.3	20.4	**23.3**	29.4	**24.8**	23.5	25.7	24.7	**24.6**	22.0	**23.9**
Turquoise	25.5	24.0	21.5	**23.6**	27.7	**24.6**	22.7	25.3	25.1	**24.3**	22.5	**23.9**
Beryl	25.9	24.9	23.5	**24.7**	—	—	23.3	26.4	24.2	**24.6**	—	—
Amethyste	24.3	24.1	20.7	**23.0**	—	—	23.1	25.5	24.9	**24.5**	—	—
Maurane	27.8	26.4	23.6	**25.9**	30.3	**27.0**	23.8	26.1	24.9	**24.9**	22.8	**24.4**
Nausica	28.9	25.5	24.9	**26.4**	31.4	**27.6**	23.7	26.7	23.9	**24.7**	22.5	**24.2**

Planting Date

By Robert G. Wilson

Chicory seed should not be planted in the spring until the soil temperature reaches 50° F. In the High Plains, this usually occurs about mid April. Planting earlier than mid April can lead to more plants bolting and an increased risk of freeze damage. In University of Nebraska–Lincoln studies, planting after May 1 reduced yield potential. Planting in mid May rather than mid April resulted in a 35 percent yield reduction.

Figure 4. *Accurately spaced chicory seedlings that have just emerged. Note each seedling has apparently emerged through where a crack now exists in the soil.*

Target Plant Population and Seeding Rate

By John A. Smith and Robert G. Wilson

Data from University of Nebraska–Lincoln plant population studies show that maximum chicory root yields occur above 80,000 plants/ac, peaking as high as 100,000 plants/ac in a 22-inch row spacing. Root yield declines steadily below 60,000 plants/ac. Production guides in Europe recommend a harvest-time plant population of 65,000 plants/ac.

A practical recommendation for plant populations in the Nebraska-Wyoming region is 60,000-80,000 plants/ac at harvest. Plant populations above this level increase root yield potential only slightly and require very close and accurate seed spacing to avoid "doubles" or "intertwined" roots that break during harvest. Small diameter roots from very high plant populations are difficult to lift, cause more root breakage and contribute to more volunteer chicory the following year. Very high plant populations also require high rates of expensive seed. Populations below 60,000 plants/ac at harvest will produce reduced root yields and less competition with weeds.

To have a final harvest population of 60,000-80,000 plants/ac, the producer needs to estimate the percentage of seeds that will produce viable plants. Laboratory germination of pelleted chicory seed under ideal laboratory conditions generally ranges from 80 percent to 95 percent. Field emergence under the best soil moisture and temperature conditions will range from 70 percent to 80 percent. Typical field emergence is usually 60-70 percent. This requires a well prepared seedbed, 3/8 inch or less seed depth, and multiple applications of irrigation water to maintain adequate soil moisture at seed depth during the entire emergence period.

It is recommended that a seeding rate of 100,000 seeds/ac (2 7/8 inches between seeds in 22-inch rows) be planted in normal field conditions to achieve a 60,000-80,000 plants/ac emerged plant population. If field emergence lower than 60-70 percent is anticipated, then a higher seeding rate should be used. *Table 5* contains emerged plant populations resulting from combinations of planter seed spacing in 22-inch rows and percent field emergence. Keep in mind that a small percentage, perhaps 5 percent, of the emerged seedlings will not live or produce harvestable roots.

Figure 5. *Rear view of the twelve-row, one-pass tillage-planting equipment system used for planting commercial chicory fields in 2005. This system includes zone tillage, application and incorporation of herbicide and planting.*

Table 5. Seed spacings required in 22-inch row width to achieve targeted emerged plant populations at different field emergence rates.

Emerged Plant Populations (plants/ac) Resulting from Combinations of Seed Spacings and Percent Field Emergence*					
Field Emergence	Planter Seed Spacings (inch) with 22-inch Row Width				
	2 3/8	2 9/16	2 7/8	3 1/8	3 1/2
100%	120,000	110,000	100,000	90,000	**80,000**
95%	117,000	104,000	95,000	85,000	**76,000**
90%	114,000	99,000	90,000	81,000	**72,000**
85%	101,000	93,000	85,000	**76,000**	**68,000**
80%	96,000	88,000	**80,000**	**72,000**	**64,000**
75%	90,000	83,000	**75,000**	**67,000**	**60,000**
70%	84,000	**77,000**	**70,000**	**63,000**	56,000
65%	**78,000**	**71,000**	**65,000**	58,000	52,000
60%	**72,000**	**66,000**	**60,000**	54,000	48,000
55%	**66,000**	**60,000**	55,000	49,000	44,000
50%	**60,000**	55,000	50,000	45,000	40,000

**The recommended established plant populations resulting from combinations of seed spacings and field emergence are shown in bold.*

Row Spacing

By John A. Smith

Current research and production experience in Nebraska and Europe support an optimum row spacing of 18-22 inches for chicory production. Data from row spacing studies conducted in Nebraska show a yield reduction of 2 ton/ac for 30-inch rows compared to 22-inch rows, other factors remaining the same. Recommended plant populations of 60,000-80,000 plants/ac require very close in-row spacing in 30-inch rows, creating undesirable competition between chicory plants. The recommended seeding rate of 100,000 seeds/ac would require a nearly 2-inch seed spacing in 30-inch rows. This, in turn, would require very accurate seed spacing to avoid tangled roots and excessive plant-to-plant competition. With wide row spacing between developing chicory plants, sunlight is wasted rather than used to promote chicory root growth. The chicory crop canopy develops slowly and narrower rows will allow chicory to compete with weeds much better, particularly later in the season. Typically, chicory plants will not develop a complete canopy between 30-inch rows, even by harvest time, allowing late season weeds to become a problem.

Nebraska research and experience indicates that an 18- to 22-inch row spacing provides optimum yields with fewer weed control problems.

Row spacings below 18 inches are not recommended with present equipment technology for several reasons. Inter-row cultivation will be necessary several times during the season for weed control. Row spacings less than 22 inches, especially with even small amounts of surface residue, are difficult to cultivate and it is difficult to properly equip an effective cultivator. Hand weeding will be necessary and it becomes more difficult to walk in row spacings less than 18 inches and more expensive to hand weed. Practical harvest equipment has not been developed for row spacings less than 18 inches. There is minimal yield advantage for row spacings below 18 inches, but a substantial advantage with changing from 30-inch to 22-inch row spacings.

Seed Depth

By John A. Smith

Optimum practical seed depth for chicory is 1/4 to 3/8 inch. Chicory seed is very small and has limited energy to contribute to moving the seedling through the soil for emergence. University of Nebraska–Lincoln research shows that seed placed 5/8 inch deep will have approximately a 50 percent reduction in emergence compared to seed placed 1/4 inch deep (*Figure 6*). Less than 25 percent of seed will normally emerge from a 1-inch seed depth. Seed placed as shallow as 1/4 or 1/8 inch will emerge very well if adequate soil water can be maintained at seed depth for the complete emergence period. If soil water content at seed depth, regardless of the depth, drops below a critical level during the emergence period, the seedling will often desiccate and die. Practical experience in both Europe and Nebraska suggests that if you cannot see an occasional seed on the soil surface behind the planter, you are probably planting too deep.

For successful emergence, a seed depth of 3/8 inch or less requires a firm, level seedbed free of large clods and residue pieces and a planter designed for shallow seeded crops. It also requires careful management of irrigation for emergence.

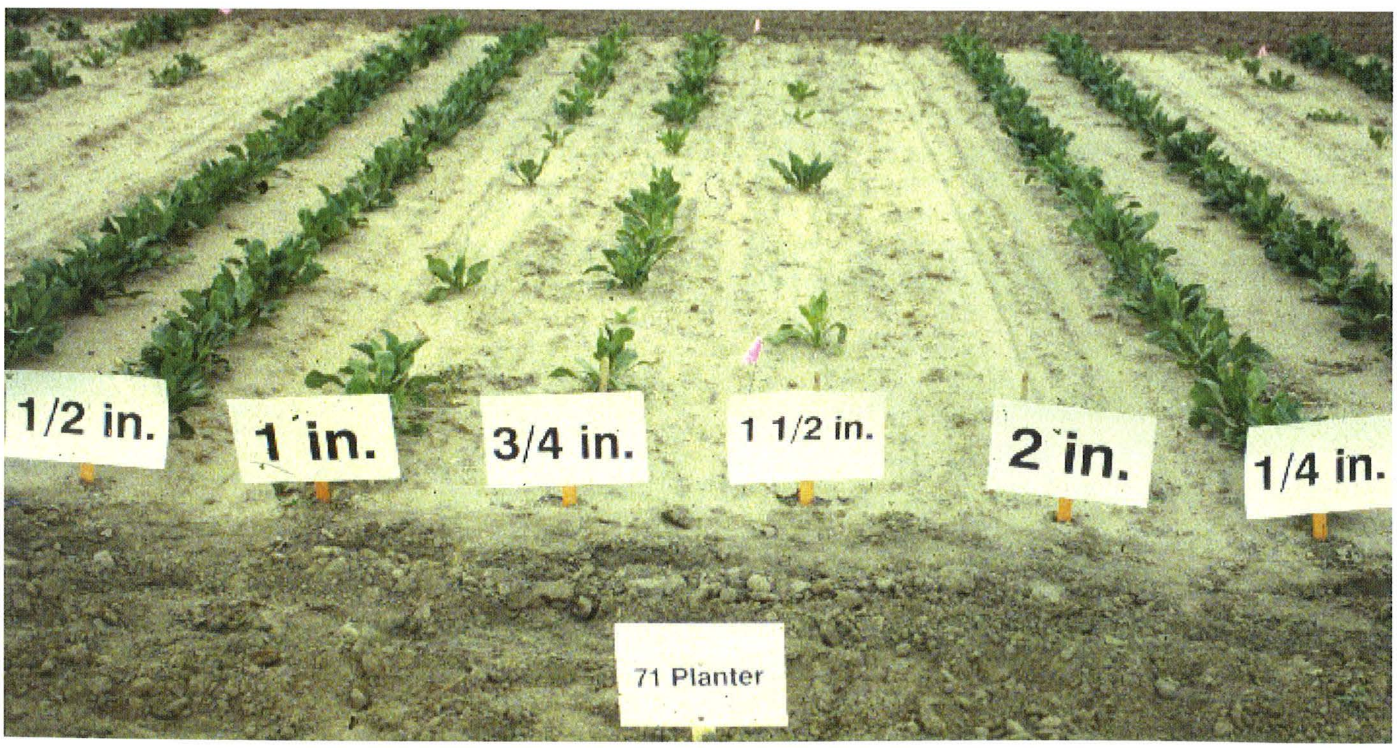


Figure 6. *Visual evidence of role of seed depth on chicory emergence. Note good emergence at 1/4 and 1/2 inch seed depth; significantly reduced emergence at 3/4, 1, and 1 1/2 inch depths; and no emergence at 2 inch depth. Plots were planted with a Deere model 71 Flexi-Planter with depth bands. Plots were sprinkler irrigated for maximum emergence.*

Planter Selection and Planting

By John A. Smith

Accurate seed depth and spacing are critical to a successful chicory crop. You cannot fix a bad job of planting other than by replanting. It is best to start with a planter designed for small seeds and shallow seed depth (*Figures 5 and 7*).

Consistent seed depth of 1/4 to 3/8 inch and accurate seed spacing are essential for good emergence, high yields and low harvest loss. Where surface residue is minimal, European style sugarbeet planters will provide the best results for chicory. These planters are designed for pelleted seed, have a very short seed drop with no seed drop tube from the seed metering mechanism to the seed furrow, and have a "speed compensation" feature that allows higher field speeds with accurate seed placement. Two examples of this type of planter include the Monosem Meca 3000 (A.T.I., Inc., Lenexa, KS) and the Kleine Unicorn-3 (Garford Farm Machinery, Deeping St. James, Peterborough, England). These planters have seed monitors and seed spacing and seed depth adjustments that are easy to change to respond to changing field conditions. A disadvantage of this type of planter is that some designs will not perform well with significant amounts of residue.

Figure 7. *Side view of combined tillage-planting equipment system used for commercial chicory planting.*

The Deere 71 Flexi-planter (previously manufactured by Deere and Co., Moline, IL) has been used successfully to plant chicory. Plates are available that will provide good seed singulation. The hoppers should be checked on a good planter test stand with the seed that will be planted to verify good performance. Optional seed tubes with sensors and a seed monitor should be added to avoid field skips. The disadvantage of this planter model is that it is time consuming to change seed spacing or seed depth when field conditions require a change. Field speed should be 2 1/2 mph or less for acceptable seed spacing with the Deere 71 Flexi-planter.

Use a planter designed for small seed and shallow planting to achieve accurate seed depth and spacing.

General purpose planters such as the Deere MaxEmerge series and the Monosem NG Plus are discouraged. The long seed drop with the small seed into a small, shallow, seed furrow offers too many opportunities to compromise seed depth and seed spacing. If a planter with a seed drop tube is used for chicory planting, it is recommended that new seed tubes be installed before planting. Seed tubes with "rough" inside surfaces will not properly direct the small seed to the bottom of the furrow. The result will be poor depth control and too many seeds on the soil surface.

Irrigation for Emergence

By C. Dean Yonts

Do not attempt to grow chicory without the ability, and more importantly, the willingness to irrigate chicory immediately after planting. Without these two things, your success at growing chicory will be in jeopardy.

Chicory seed is planted very shallow in the soil, less than 3/8 inch, and keeping the soil surface moist immediately after planting is critical for germination. This is best accomplished by having adequate soil water below the seed. Water held below the seed migrates up toward the soil surface to evaporate. This constant upward movement maintains soil water at seed depth, allowing for a more uniform uptake of water by the seed and an increase in the potential for germination during this critical period.

Chicory can be grown using both furrow and sprinkler irrigation systems. Providing soil water below the seed is easier when furrow irrigation is used after planting. Furrow irrigation allows the seed and soil to be wetted and at the same time store an abundant amount of water just below the seed. In this situation the upward movement of water can occur for several days, as seen from the re-wetting of the soil surface in the early morning hours in the days following initial irrigation. Studies have shown that, due to these soil water dynamics, very good germination is obtained using furrow irrigation.

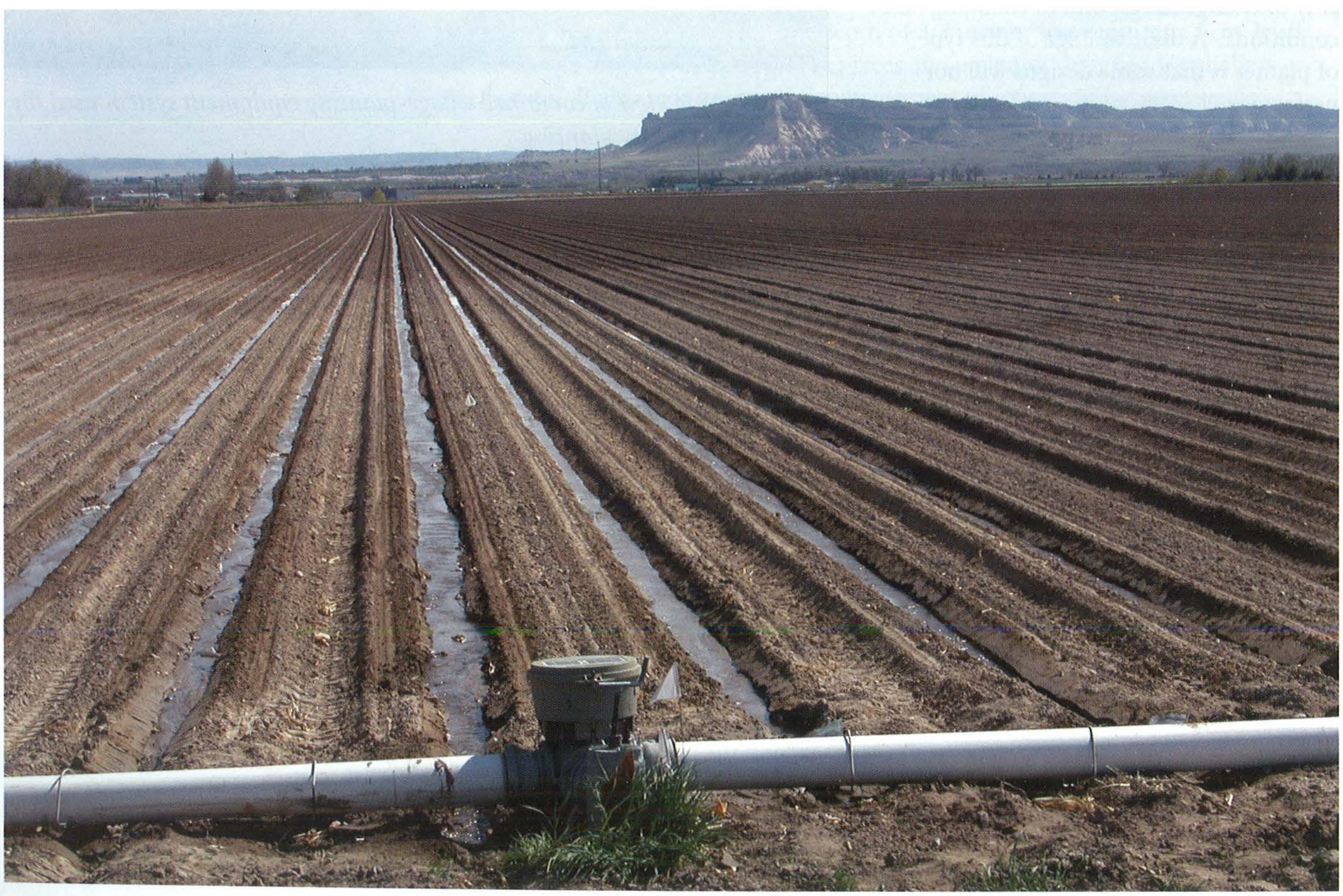


Figure 8. *Surge valve used for furrow irrigation to irrigate the planted chicory crop for emergence.*

When using furrow irrigation, growers need to pay particular attention to soil and residue conditions at planting. The ability to irrigate after planting is essential, so select furrow irrigated fields that allow early season irrigation (*Figure 8*). Preparations for irrigation should be completed within one to two days after planting. A rainfall event after planting can begin the germination process, but without additional rain or irrigation, seeds planted close to the soil surface can dry quickly. As a result, it may only take a couple of days before seed dessication occurs. Because of the need to be able to irrigate soon after planting, plant on beds to avoid having to create furrows after the seed is planted. Avoid furrow irrigation on 30-inch rows. This wide spacing makes it difficult to wet the soil at seeding depth because of the distance water must move at the soil surface.

Maintaining a moist soil surface after planting is critical to successful chicory germination. ■

Furrow irrigation is labor intensive compared to center pivot sprinkler irrigation, and sprinkler systems provide the opportunity to apply light applications of water and more easily replenish the surface water held near the seed. The key to good germination and emergence with sprinkler irrigation is providing adequate water below the seed, as discussed in the previous paragraphs, without causing excessive destruction to the soil surface which could result in crusting.

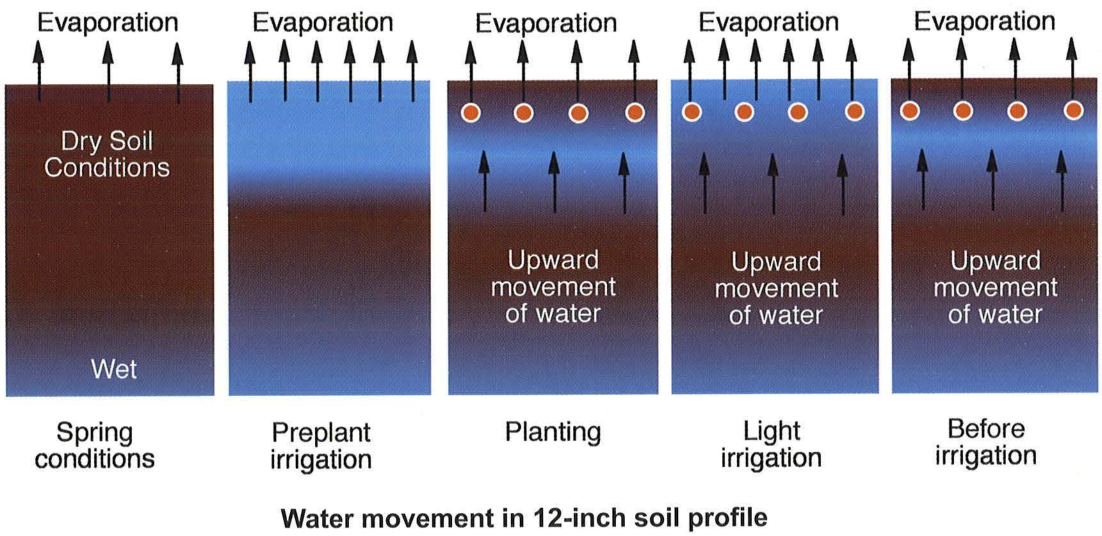
When using sprinkler irrigation in dry soil conditions, irrigations before planting and wetting the top 12-18 inches of soil provide three primary advantages. First, applying water before planting allows seed to be more precisely placed in a firm and moist soil condition. Second, soil water is immediately available to the seed to begin the germination process. Third, and most important, it will not be necessary to apply an excessive amount of water to wet the soil after planting. As the soil surface dries, only light applications of water will be needed to replenish water evaporated from the soil surface.

Heavy sprinkler applications can lead to the destruction of soil structure at the soil surface, causing crusting and increasing the potential for wind erosion. Trying to apply all of the water necessary for seed germination after planting means that several applications of water will need to be applied. Water applied in the top 1-2 inches of a dry soil means that a portion of the water will migrate to the surface to be evaporated. The other portion is quickly drawn downward as the soil tries to reach equilibrium with the soil below. This situation results in soil water being pulled away from the seed in two directions.

The number of irrigations to complete emergence will depend on the weather conditions, soil type and the irrigation system used. On medium textured soils, one, and probably two, furrow irrigations will be needed. The time interval between the irrigations will likely be three to five days, depending on climatic conditions. Using a sprinkler system and having adequate water in the subsoil will require three to five passes with the sprinkler. If conditions are cool in the spring, 0.3-inch applications may be adequate while warmer spring conditions may require 0.5-inch applications to make up for additional evaporation losses. It is recommended that for a 120-acre center pivot, a minimum pumping capacity of 500 gal/min be available. With a 500 gal/min pumping capacity, approximately 0.5 inch of water can be applied in 2.5 days. Given this capacity, it would be advisable to irrigate before planting to recharge the soil profile.

Figure 9 shows how irrigation before planting can be important for obtaining good emergence of chicory under a center pivot. In the example, spring soil conditions are dry. By applying a pre-plant irrigation, the top 12 inches of the soil profile can be partially filled with water to aid in germination and emergence. After the soil surface dries, chicory can be planted in a firm, moist seedbed. An immediate irrigation after planting refills the soil profile around the seed and starts the germination process. Water that is held in the subsoil constantly moves toward the soil surface to be evaporated. When the surface has dried to seeding depth and the upward movement of water to the seed has slowed, a second irrigation should be applied to re-wet the soil around the germinating seed. Because water is available below the seed, irrigation is needed to just replace the water that was evaporated from the soil surface. The process of replacing water that is evaporated from the soil surface continues until emergence is complete.

Figure 9. Diagram depicting soil water movement after a preplant irrigation and successive irrigations for good emergence of the chicory seed.



If adequate soil water is present, germination will normally require only seven to ten days. Once germinated, the plant quickly roots into the soil and begins to use water stored deeper in the soil. Again, weather conditions during plant establishment will dictate the amount and timing of irrigation that is needed. But remember, a small seed placed very near the soil surface can quickly dry if adequate water is not available in the soil profile.

Under a sprinkler irrigation system, residue may be a concern if it affects the desired seed depth and seed spacing. The residue itself can help in germination by slowing the rate of water being evaporated from the soil surface. In addition, the residue will dissipate much of the energy from the water during sprinkler irrigation and help reduce the potential for crusting. With furrow irrigation, however, residue can slow stream advance and make the critical first irrigation difficult.

Diseases and Disease Control

By Robert M. Harveson

At the time of this writing, few disease problems have been noted in Nebraska's chicory production. Several diseases have been consistently identified from production fields, but none are considered to be yield-limiting.

Two distinct root rots, caused by *Erwinia spp.* (bacterial soft rot of taproot) and *Phoma exigua*, have been observed in Nebraska each year since 2001. The bacterial soft rot is not usually seen until mid to late summer when soil temperatures reach their highest levels. Affected plants are found scattered throughout fields, primarily in lower areas where water tends to accumulate. Foliar symptoms of bacterial root rot consist of permanent wilting and collapse of leaves and petioles, with a slimy, wet rot of taproots starting at the distal tip. The Phoma root rot is caused by a soilborne fungus and has only been observed the following spring on volunteer roots left over winter. Symptoms include black lesions, varying in severity and root surface area affected. Other diseases observed in the region include both bacterial and fungal leaf spots, caused by *Psuedomonas spp.* and *Alternaria spp.* (*Figure 10*), respectively, and another root rot caused by the soilborne fungus *Rhizopus* (*Figure 11*).

Figure 10. Alternaria *leafspot is caused by a fungal pathogen.*

Numerous diseases in chicory have been reported worldwide, including several bacterial leaf spots and *Erwinia* (bacterial) root rot. This disease appears to be similar to the bacterial soft rot disease recently found in Nebraska and Wyoming. Another 35 to 40 species of fungal pathogens also have been known to attack chicory, including those causing both root rots and foliar blights. Chicory is also susceptible to several virus diseases such as cucumber mosaic and tomato spotted wilt. Common nematodes also have been reported infecting chicory roots, including several species of root-knot nematodes (*Meloidogyne*), lesion nematodes (*Pratylenchus*) and the sugarbeet cyst nematode (*Heterodera schactii*). These are all known to occur in western Nebraska and eastern Wyoming on other crops.

Figure 11. Rhizopus *root rot is caused by a soil-borne fungus. Note the watery rotted crown and petioles and the grayish mycelium spreading across the soil surface.*

Fortunately, all diseases found in this area appear to be minor in nature and limited in distribution to isolated areas of production fields. Some of these pathogens, including *Erwinia spp.*, *Phoma spp.*, and several nematodes, have additionally been reported causing disease in sugarbeet. It is not known at this time how this may affect either chicory or sugarbeet production, but these rotation issues and the potential appearance of other diseases will likely become more important as chicory acreage increases throughout the Central High Plains. Close surveillance of fields for the appearance of new and emerging disease problems is warranted and will continue.

Insects and Insect Control

By Gary L. Hein

Few insects have been found to cause problems in chicory. The only insect problem that we have seen has been early season cutworm infestations, however, in some years other general feeders, such as grasshoppers, may cause problems in hot-spot areas. The potential for these problems must always be considered as the crop progresses through the season.

Cutworms are general feeders that feed on numerous hosts. In addition, multiple species of cutworms can be present during the spring when chicory is being established. The most important species of cutworms in western Nebraska overwinters as partially grown larvae, and as a result, they can feed extensively while the crop is establishing. Because chicory emerges and grows slowly during early establishment, these actively feeding cutworms can rapidly reduce stand. The most common cutworm species present during the spring in this region include the army cutworm, pale western cutworm, dingy cutworm and dark-sided cutworm.

Army cutworm adults lay their eggs over an extended period in the fall in loose open soils. Cutworms (*Figure 12*) feed in the fall and winter when temperatures are favorable; therefore, they will only survive in fields and field margins where green plants are available through the late fall and winter (for example, winter cereals and cool-season grasses). By early May, cutworms will be nearly full grown (1 1/2 to 2 inches long). Chicory may be damaged when cutworms move from adjacent fields or grassy borders into emerging fields. More importantly, severe stand reduction can result if chicory is planted directly into winter cereal (primarily winter wheat) cover crops. By mid May, the risk of damage from these cutworms declines.

Figure 12. *Pale western (top) and army cutworms (bottom).*

Pale western cutworm adults also lay their eggs in September and are attracted to freshly tilled loose soil. Because of this habit they are most common in winter wheat fields. In early spring, warm temperatures initiate hatching and cutworms will develop through April and May (*Figure 12*). These insects are only likely to occur in significant numbers in winter cereal fields; therefore, they are only a threat to chicory in fields planted previously into winter cereal cover crops.

Dingy cutworm moths lay their eggs in late summer. The eggs hatch and cutworms feed into the fall and then go dormant for the winter as partially grown cutworms. These cutworms begin feeding in the spring as temperatures warm and develop into early June. They feed mainly on weeds, such as mustards, during the fall and seldom build up to high populations.

Dark-sided cutworms overwinter as eggs, begin to hatch in May, and feed through May and June. Because they are small during chicory establishment, damage from these cutworms will develop more slowly than with other cutworms.

Nebraska chicory has few insect problems, although high populations of cutworms can lower yields, especially in fields previously planted to cereal cover crops. ■

Low densities (1 per 20 row feet) of the early spring-feeding large cutworms can cause rapid stand loss (5 percent or more per night). Damage symptoms are difficult to notice on small plants (*Figure 13*), and often the only sign of cutworm damage is a reduction in stand. Larger larvae can consume multiple plants each night, but small larvae will have a much more gradual effect on stand. Damage is indicated by the presence of notched or missing leaves, and plants may be killed outright if the growing point has been eaten, leaving only a stub behind.

There are few management options available to reduce the severity or damage potential of cutworms. Chicory planted into a winter cereal cover crop is at a very high risk for cutworm damage. If these cover crops are used, consider treating for cutworms when spraying herbicides to kill the cover crop. Chicory planted into fields left clean-tilled over the winter will be at low risk for cutworm damage. Fields should be scouted during establishment so the extent of infestation and damage can be assessed. Because cutworms are difficult to detect, scouting must include some attention to the progression of emerging plants. If emergence is delayed or stand density starts to decline, the problem must be thoroughly evaluated and immediate action taken. In some years, cutworm movement out of border grasses also can be significant. In these areas, scouting should include a check of border grasses for defoliation of new plant growth.

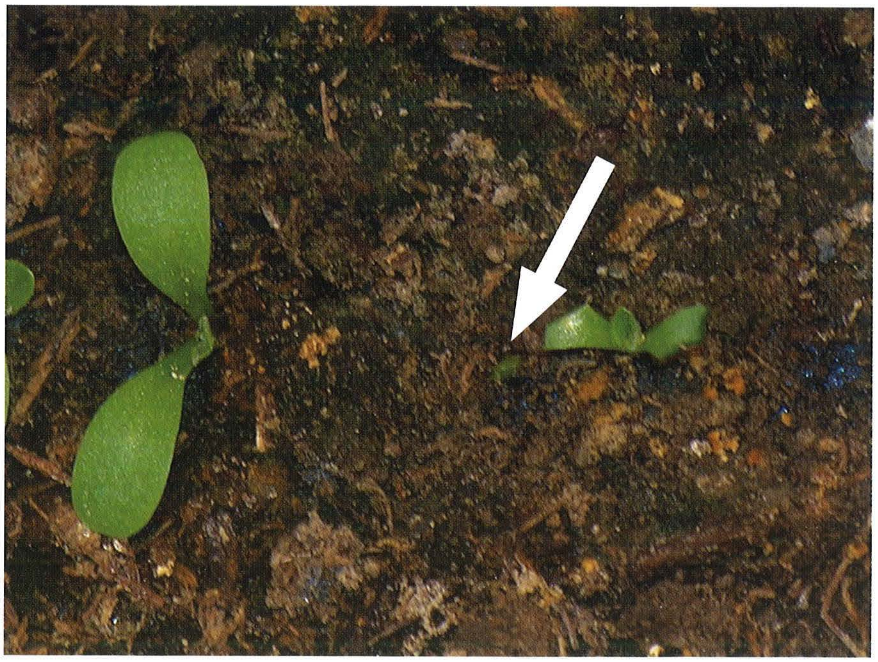


Figure 13. *The chicory plant on the left is healthy while the two plants to its right have been damaged by cutworms. In the middle, only a stub of the chicory plant is left after a cutworm clipped it off at the base. The plant on the far right exhibits leaf damage from cutworms.*

Treatment options in chicory have been limited, but recent expansions of some pyrethroid product registrations for "root vegetables" (including chicory) provide good options for cutworm control. These materials include beta-cyfluthrin (Baythroid), cyfluthrin (Renounce) and deltamethrin (Decis, Delta Gold).

Irrigation During the Growing Season

By C. Dean Yonts

Once established, chicory water use will be similar to other crops planted in the spring. Water use will slowly increase to approximately one inch per week by early to mid June. By late July, water use will peak at approximately two inches per week. Because chicory grows well into early fall (*Figure 14*), water use will remain relatively high through October 1, at about one inch per week, if climate conditions are favorable.

Chicory will obtain the majority of its water from the top three feet of the soil profile. In a medium textured soil with a water holding capacity of two inches, approximately one inch is available to the plant without having stress. Therefore, in a three-foot soil profile, three inches of water can be stored and used by the plant. It is best to maintain a schedule of irrigations that will meet the needs of the crop without over irrigating.

As the chicory grows, lower leaves tend to grow in a somewhat prone position. For furrow irrigation this means that moving water in the furrow will become more difficult later in the growing season.

By mid June chicory is consuming one inch of water a week and by late July, it needs two inches. It will continue needing water into early October. ■

Like any root crop, soil water condition at harvest can influence harvest efficiency. Too wet and it will be difficult to separate the soil from the chicory. Too dry and roots may snap in the soil, leaving a portion of the crop in the field. To create the desired conditions for harvest, it will be easier to apply water with sprinkler irrigation than with furrow irrigation.

One critical component for growing chicory is the water source. In the North Platte River Valley, early water for irrigation is sometimes questionable when water is obtained from the canal systems. A reliable supply of water is necessary if chicory is to be grown. When snowpack is limited and the likelihood of early water in the canal is doubtful, the only alternative is to grow chicory when groundwater pumping can supplement or supply the crop's seasonal water needs.

Figure 14. *Close-up of chicory leaves in late August.*

Harvest

By John A. Smith

Chicory roots are usually harvested in late September and October. The date of harvest can have a substantial influence on root weight and carbohydrate content. Root yield can double from the first of September to mid November (*Figure 15*). As roots increase in size, the quantity of long-chain inulin polymers also increases until about mid October. After the first hard frost in the fall, the quantities of short-chain inulin increase while long-chain polymers decrease. This is extremely important for the factory processing the crop for inulin with different chain lengths since chicory roots can contain 70 percent inulin on a dry matter basis. If the processor is not interested in chain lengths and only root yield, later harvest dates will provide greater root yields. Therefore, the chicory processor and grower must schedule the harvest to provide the grower with a return on investment and the processor with the raw materials that meet specifications.

Although there are some similarities between harvesting sugarbeet and harvesting chicory, the roots of the two crops are very different and require different harvesting equipment. Chicory roots are much smaller in diameter and longer than sugarbeet roots. Chicory roots resemble large carrots. A chicory harvester (*Figure 16*) can harvest sugarbeet, but a sugarbeet harvester cannot harvest chicory without major modifications. In addition, the soil and field conditions necessary for a successful chicory harvest are different than those needed for sugarbeet.

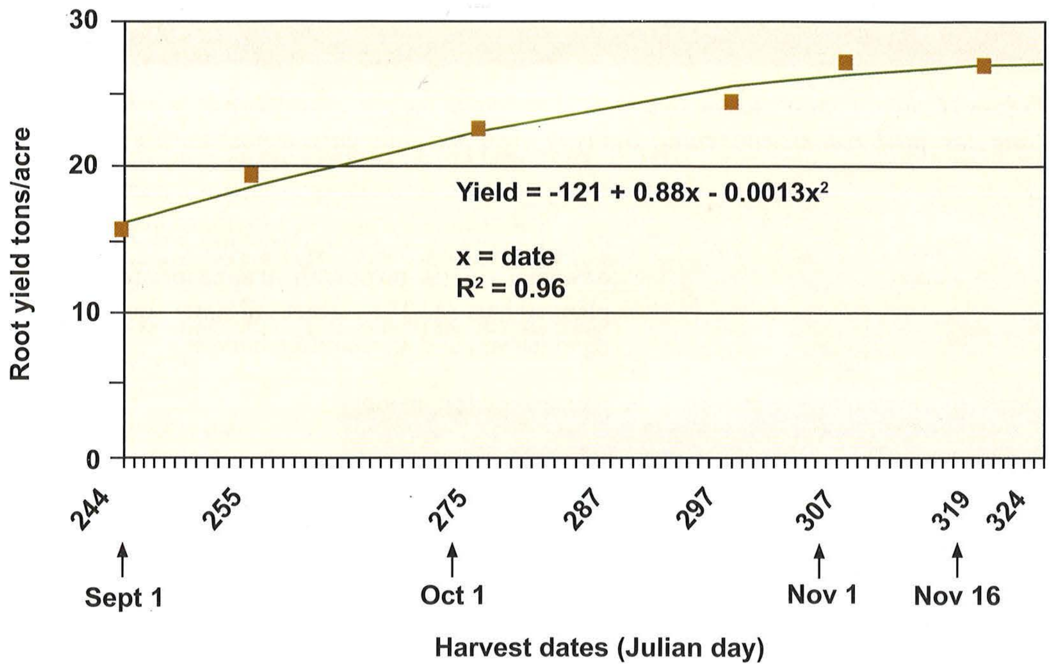


Figure 15. *Yield of chicory roots at various times during the harvest season.*

Soil Water Content at Harvest

Chicory roots are more difficult to lift from the soil than sugarbeet roots. To minimize field loss, the soil cannot be too dry or too wet. If the soil is too dry, roots will often break off four to eight inches below the soil surface, creating high field loss, low harvested yield and a severe volunteer problem the following year. If the soil is too wet, trucks and equipment get stuck and cause soil compaction, and the root soil tare (soil that adheres to the roots) will be high.

Check the field several days or a week before planned harvest. A shovel is one of the best tools to determine if the soil moisture is in the correct range for harvest.

Figure 16. *Rear view of custom operated, commercial six-row 22-inch chicory harvester. Note close pitch rear elevator chain and very few broken root parts behind the harvester.*

Loosen the soil around the root to a depth of about 8 inches. If the shovel does not push into the soil easily, the soil is probably too dry. Next, with the soil around the root loosened, you should be able to carefully pull the root straight up by hand without breaking the root tail for a root length of at least 14 inches. If the root cannot be pulled by hand without breaking the tail, the harvester probably can't lift it either, and the soil is too dry. At the other soil moisture extreme, the soil should not be so wet that excessive soil clings to the root, or that tractors and trucks make ruts or get stuck in the field. If the soil is too wet, consider delaying harvest. If it is too dry (and if the field is pivot-irrigated and has a source of water), run the pivot with an appropriate application rate about a week before planned harvest. The correct soil water content will make the difference between a good harvest and a frustrating harvest.

Defoliating the Roots

Sugarbeet defoliating equipment will satisfactorily defoliate chicory. One difference is that the top of sugarbeet roots typically extend several inches above the soil surface. Chicory roots normally do not extend above the soil surface and require the defoliator flails to contact the soil surface, creating more wear on flails than when defoliating sugarbeet. Three-drum defoliators, with one steel flail drum in front and two rubber flail drums in the rear, have worked well in Nebraska and Wyoming. If the plant leaves have been frozen and are "raggy," three rubber flail drums would probably work better.

The ultimate use and processing method for the chicory roots determine whether scalping is required. Because the roots do not extend as far above the soil surface as sugarbeet roots, the standard knife-type scalper tends to plug with leaf material in chicory. A powered, rotary scalper has been used successfully for scalping chicory roots without plugging.

Check with the processor to determine if scalping is required or not allowed. Scalping does remove the unwanted root crown and any leaf material. Scalping will reduce yield and the small crown pieces often will grow the following year, creating excessive volunteer chicory. The fresh cut surface also tends to collect soil and small rocks that may interfere with the processing.

Lifting the Roots

A modified sugarbeet harvester has been found to satisfactorily lift, clean, and load chicory roots, even relatively small diameter roots from a field with nearly 100,000 plants/ac. There are several differences between chicory roots and sugarbeet roots that necessitate modifications to a sugarbeet harvester.

1) Chicory roots will be smaller in diameter than sugarbeet roots, requiring smaller openings where small roots might fall through the harvester. Roots and root parts as small as 1/2 inch in diameter should be carried through the machine.
2) The harvestable length of chicory roots will be longer than sugarbeet roots. The harvestable length of many roots will be 16-20 inches. This requires careful and directed lifting from the soil to prevent breakage.
3) Chicory roots tend to be more fragile than sugarbeet roots, partly because of their relatively small diameter and long length. These fragile roots require delicate handling within the harvester to prevent breakage and loss of part of the root.
4) The crowns of the chicory roots do not extend above the soil sufficiently to allow the harvester row finder to register and guide the harvester. Operators must rely on accurate tractor driving and manually aligning the harvester using the tractor hydraulic controls.

Chicory roots are longer, smaller in diameter and more fragile than sugarbeet roots and must be pulled straight up, necessitating modifications to any sugarbeet harvester before it can be used in chicory. ■

Modifying a Sugarbeet Harvester for Harvesting Chicory

A harvester with a grab roll cleaning bed and squeeze-chain elevator (*Figures 16 and 17*) is recommended over a harvester with a "wheel"-type elevator because it has been easier to reduce root breakage and retain small root parts in a squeeze-chain elevator. Four general changes are recommended to convert a sugarbeet harvester to a chicory harvester.

1) All conveying and squeeze chains and associated sprockets must be removed and replaced with narrower pitch chain, usually 1 1/4- to 1 3/8-inch pitch chain, depending on the soil type and size of roots to be retained in the machine. Sugarbeet harvesters are normally equipped with a 1 3/4- to 2 1/4-inch pitch chain that will leave an unacceptable trail of chicory roots behind the harvester. If the machine is equipped with a bed chain between the lifting wheels and the grab roll bed, use a special "block-type" chain (*Figure 17*) that has short sections of regular narrow pitch and adjacent sections of effectively wider pitch. The wider, but short, openings allow much more soil to drop out, but the long chicory roots do not drop through because of the amount of soil being carried and because the roots are positioned horizontally on the chain.
2) The grab rolls need to be made less aggressive to reduce root breakage and must be closer together to retain the smaller roots. This may require smaller diameter scrolling on the grab rolls to reduce breakage, and larger diameter rolls to reduce the spacing. Depending on the grab roll design and the performance, adjusting grab roll rpm and adding sections of scrolling may help root movement and reduce root breakage.

Figure 17. *Modified apron chain between lifter wheels and grab rolls of commercial chicory harvester. Note that every other rod has been removed from the original chain and short stubs have been added in the perpendicular direction. This allows soil to drop out but still retains the small roots.*

3) All transition areas within the machine, such as between the grab roll bed and the elevator, must be examined and modified if necessary to prevent breaking or losing roots.
4) Lifter wheel configuration may require modification to achieve acceptable root lifting. Typically, the wheels should be as large in diameter as possible—32 inches is preferred over 28 inches. The wheels should have a pronounced bevel on the rim and the rim should be relatively wide to provide maximum squeezing action to gently lift a ribbon of soil, and with it, the roots.

Figure 18. *The "pinch point" of the chicory harvester lifter wheels should be adjusted carefully, both wheel spacing and vertical position. Excessive wheel spacing may not lift some smaller diameter roots, while very close wheel spacing may cause root breakage if the machine is not accurately centered on the chicory row.*

Figure 19. *Chicory root "tails" broken during harvest. The lifter wheels were only slightly off center compared to the chicory row, did not pull the roots straight up, and caused the roots to break. These broken tails will reduce yield and cause volunteer chicory the following year.*

The wheel pinch point may need to be rotated higher because the roots are longer and need to be lifted higher before being tipped. The spacing of the wheels at the pinch point (*Figure 18*) may need to be adjusted for the best compromise of maximum lifting action and minimum root breakage (*Figure 19*) caused by the wheels not being centered on the chicory row. Often a pinch point clearance of 2.5-3 inches will reduce root breakage compared to a clearance of 1 3/4 inches more typical for sugarbeet. The tapered sugarbeet roots nearly "pop" out of the soil with a little lifting pressure by the lifter wheels. Chicory roots have far less taper (*Figure 20*) and need to be gently lifted for a longer distance before they are ready to tip onto the grab roll bed or chain bed.

Observe roots as they move from the lifter wheel to the chain bed or grab roll bed. If the roots are not lifted high enough, they will be broken. If the paddle is too aggressive, they can be broken before they are released from the soil or as they contact the chain or grab roll bed.

European chicory harvesters that use Oppel wheels for lifting the roots often will have a single, narrow shank positioned several inches from one side of the chicory row, and just ahead of the lifter wheels. This shank operates from 8 to 14 inches deep and serves to loosen the soil and root to minimize root breakage by the Oppel wheels. These shanks normally have a "bullet" shaped tip, 6-8 inches long, with the front point tipped slightly lower than the rear.

Experience in Nebraska and Wyoming has shown that the standard row finder mechanism on a sugarbeet harvester is not reliable because it does not register adequately on chicory roots. No alternatives have been developed for U.S. harvesters. Because the roots are so long and lack significant taper, they must be pulled straight up. If the root is pushed sideways by lifter wheels not centered on the row, the root will often break several inches below the soil surface. A sugarbeet harvester can be "off the row" as much as 2 inches and normally will not break the sugarbeet root. Lifter wheels misaligned by as little as 2 inches while harvesting chicory roots often will break a high percentage of the roots. Until suitable equipment developments provide a solution, accurate cultivation that leaves a good mark for the harvester tractor to accurately position the lifter wheels and constant observation by the operator will be the best alternative. Eventually, planting and harvesting with sub-inch level auto-steer systems may provide a good solution. European chicory harvesters include defoliating and lifting in the same operation. The guidance mechanism of European machines registers on the base of the leaves just above the root in two or more rows at the front of the machine to provide guidance. Since U.S. harvesters separate defoliating and lifting into two machines, this approach is not an option for U.S. style lifters.

The chicory processor's priorities for either root yield or inulin chain length should help determine harvest date. Root yield can double from early September to mid November. ■

Because the number of chicory roots per acre is high, often two or three times higher than sugarbeet plant population, a small percentage of broken or sliced roots can add up to a significant field loss. This field loss will reduce effective yield and contribute to a volunteer chicory problem in the following crop. The chicory harvester must be designed and operated to minimize broken tails and loss of small roots and root parts.

Figure 20. *Typically shaped and sized chicory roots pulled in mid August. Note these roots are longer and more "carrot shaped" than sugarbeet roots. At harvest time these roots will often be 16-24 inches long when lifted.*

Storage of Harvested Roots

By John A. Smith and Robert G. Wilson

Unlike sugarbeet roots, chicory roots do not store well once they are harvested. Factors such as root temperature when piled, air temperature, air flow through the pile, pile size, root damage, and amount of soil on the roots will influence storage life. Inulin breakdown within the roots will begin, although relatively slowly, as soon as the roots are removed from the soil. Depending on the intended use of the chicory roots (slicing and drying or inulin extraction) and on storage conditions, maximum storage time in an outdoor pile is only one to two weeks. Ideally, chicory roots should be processed within several days of harvesting to achieve the highest quality product.

Post-Harvest Field Operations

By John A. Smith and Robert G. Wilson

The harvested chicory field should be roughened or tilled and then planted to a cover crop (if time allows) to avoid wind erosion during the following winter and spring. Because the soil normally will have a high water content at harvest time, and since large trucks are used to load the chicory in the field, soil compaction the following year is a concern. It is recommended that the field be deep moldboard-plowed or deep ripped unless a zone or strip tillage implement will be used before planting the next crop. For effective deep ripping, the soil must have a low soil water content, which may not occur before the next crop is planted. For that reason, deep ripping usually will not be an effective operation following chicory harvest.

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Control of Volunteer Chicory in the Crop Following Chicory

By Robert G. Wilson

Volunteer chicory plants (*Figure 21*) that arise from roots broken off at harvest and left in the field may appear for one to two crop years following the chicory crop. Best control programs include applying Stinger, Curtail, or Distinct in a growing corn crop or Curtail in a growing cereal crop. Roundup (glyphosate) utilized in a Roundup Ready cropping system has not been an effective herbicide to control volunteer chicory. Between-row cultivation, using a wide sweep blade 4 to 6 inches deep when the corn is as tall as possible, will kill many emerging volunteer chicory plants between the corn rows. This is an effective way to kill volunteer chicory. A useful strategy is to intentionally plant the following row crop in rows positioned between the rows of the previous chicory crop so cultivation can remove much of the volunteer chicory, especially if the volunteer chicory is still in rows.

Figure 21. *Volunteer chicory emerging the year following the chicory crop now competes with the corn crop. This field was not moldboard-plowed. Both the chicory and corn were planted in 22-inch rows. Note almost all of this volunteer chicory is in the original chicory rows, probably originating from root tails broken during harvest.*

It is important to remember that cultivation needs to be combined with postemergence herbicide application to control volunteer chicory. Volunteer chicory plants do not emerge at the same time — some will emerge with the crop and some later in the season. Emergence is dependent on where the chicory root is positioned in the soil. Root tips located 12 inches below the soil surface may take 15 to 20 days longer to emerge than roots located near the soil surface. Because of uneven volunteer chicory emergence, two postemergence applications of herbicides in the crop following chicory may be necessary.